Application of the SEBAL Methodology for Estimating Evapotranspiration and Consumptive Use of Water Through Remote Sensing

Phase III: The Transition to an Operational System

Idaho Department of Water Resources
University of Idaho, Department of Biological and Agricultural Engineering

Submitted to

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1.0 Executive Summary

The Surface Energy Balance Algorithm for Land (SEBAL)
SEBAL is a satellite image-processing model for computing evapotranspiration for large areas. SEBAL is comprised of twenty-five computational steps that predict a complete radiation and energy balance for the earth's surface. SEBAL uses digital image data collected by Landsat or other satellites measuring visible, near-infrared and thermal infrared radiation.

Linkage Among Phases I, II, and III
The linkage among the first three phases of Synergy is the need for an inexpensive, accurate, and quick way to map evapotranspiration.

Objectives for Phase III
Phase III had seven objectives: 1) relate crop yield to evapotranspiration (ET); 2) enhancement of the SEBAL web site; 3) development of SEBAL training materials; 4) testing of SEBAL as a regulatory tool; 5) evaluate SEBAL ET as a component of the lower Boise Valley ground water model; 6) complete the year 2000 ET map for southern Idaho; 7) transfer SEBAL technology to Idaho State University.

User Community
The user community is the Idaho Department of Water Resources (IDWR), and other water organizations such as the U.S. Bureau of Reclamation, canal companies, irrigation districts, and other water measurement organizations.

New Product Development
Yield functions were assembled for Idaho crops from literature to help farmers evaluate relative yield losses stemming from ET stresses. Two levels of training were created for SEBAL, expert level training and introductory training. Training materials have been created for each group.

SEBAL as an Operational Tool
IDWR presently has the technical means to identify diversions not having a water right, but not the technical means to identify someone using water "in excess of the elements or conditions of a water right". The results of Synergy Phases II and I have convinced IDWR water managers that SEBAL can reliably and accurately derive ET as an operational regulatory tool for administering water rights. Two July, 2002 Landsat scenes were processed and delivered to IDWR 11 days after the second overpass date. Some 426 water rights compared with SEBAL-generated ET, and 18 of those were found to have ET greater than the water right could provide. The User concluded that SEBAL estimates of water consumption appear accurate and consistent, and that the User should consider continued use of SEBAL in future years for determining total annual water consumption and in identifying excessive irrigation diversions.

Year 2000 ET Map of Southern Idaho
This project was funded largely by the U.S. Bureau of Reclamation to complete the year 2000 ET map for southern Idaho. This product has had the

Transfer of SEBAL to Idaho State University
Idaho State University (ISU) now has access to SEBAL. Ten ISU faculty and graduate students completed the SEBAL expert training in August 2002. An ISU graduate student has successfully ported SEBAL to the IDRISI remote sensing package, which is running at the ISU GIS and remote sensing lab.

Web Development
The part of the IDWR Synergy project website has received 1,158 site visits between April 1, 2001 and October 31, 2001. The existing Synergy web site was augmented to include a mosaic of false-color composite of TM data and cumulative ET data for the study area; a tool to clip and download the ET and TM images for a polygon; and SEBAL ET for existing polygons such as water rights.

Lessons Learned
First, new technology can work better than the old and well-used components. IDWR was able to get SEBAL ET data within its designated time frame, but the analysis of ET by water right was hampered by IDWR's water right data-model, which is not optimal for such analysis. Second, unexpected uses for a data set can turn out to be extremely important. The IDWR planners found ET by land use/land cover class to be a product for which they have a critical need.

Synergy with Other Infomarts
Yield functions were assembled for Idaho crops from literature to help farmers evaluate relative yield losses stemming from ET stresses as reflected in ET. UI personnel reviewed the yield work done by Dr. George Seielstad of the University of North Dakota Synergy Project. The information gleaned from working with North Dakota Synergy personnel was incorporated into the results discussed in Section 4.2. University of Idaho personnel processed a Landsat scene for the University of North Dakota Synergy Project.

Potential Activities for Phase IV
1) Computation of surface roughness for residential land and rangeland will improve SEBAL's performance; 2) those improvements will enable IDWR to make refinements in the year 2000 ET values for the Boise Valley; 3) the SEBAL model has been ported to IDRISI, but before it is released, it needs to be validated; 4) establishing SEBAL as an institutional water resource tool.

Publications
Nine publications resulted from Phase III, including two Ph.D. dissertations.

Presentations
Seven presentations were made.

Appendix B: Student Involvement
Synergy Phase III supported three Ph.D. students and one Master's student.

2.0 Introduction

2.1 The Surface Energy Balance Algorithm for Land (SEBAL)

SEBAL is a satellite image-processing model for computing evapotranspiration maps for large areas. SEBAL is comprised of twenty-five computational steps that predict a complete radiation and energy balance for the earth's surface along with fluxes of sensible heat and aerodynamic surface roughness. SEBAL uses digital image data collected by Landsat or other remote-sensing satellites measuring visible, near-infrared and thermal infrared radiation. Evapotranspiration (ET) is computed as a component of the energy balance on a pixel-by-pixel basis. A general schematic of the SEBAL process is illustrated in Figure 1. A detailed description of the model is provided in Bastiaanssen et al. (1998a), Bastiaanssen (2000). Phase I of this study, entitled "Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the Bear River Basin of Idaho through Remote Sensing" (Morse et al., 2000), demonstrated the ability of SEBAL to create ET maps for large areas in the Bear River Basin of Idaho, Utah and Wyoming. The report is available at www.idwr.state.id.us/gisdata. Phase II extended SEBAL to the Eastern Snake River Plain, analyzing twenty times more data than Phase I.

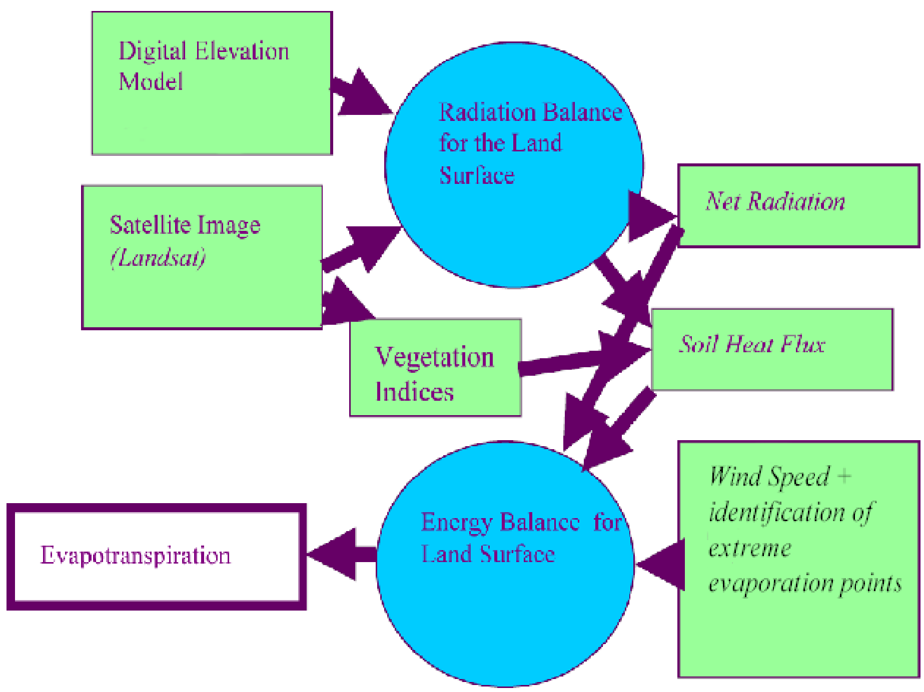

Figure 1. Schematic of the general computational process for determining evapotranspiration using SEBAL

For SEBAL to become operational, there needs to be demonstrated utility to business processes of IDWR (and other entities), particularly in regard to water rights management and ground-water modeling and planning. ET predictions, coupled with surface-water diversion records and estimates of ground-water pumpage, may allow the evaluation of 1) the relative efficiency of projects (i.e., fraction of diverted water that is evaporated); 2) the distribution in space and time of incidental recharge, which is a residual of diverted water; 3) the change in time of year and between years for these various performance indicators; and 4) impacts of timing of return flows from irrigation projects on downstream discharges and consequent predictions for salmon recovery and impacts on other endangered species.

2.2 Linkage Among Phases I, II, and III

In the broad sense, the linkage among the first three phases is the need for an inexpensive, accurate, and quick way to map evapotranspiration. Phase I was a preliminary evaluation of just such a method that had been developed in Europe (SEBAL). The results of Phase I were good enough to warrant a more detailed evaluation with a large data set. Phase II was the detailed evaluation, and the results of Phase II convinced IDWR management that SEBAL was viable for mapping ET. However, using SEBAL to map ET and using SEBAL operationally as an administrative tool are different issues. Therefore, the most important aspect of Phase III for IDWR was the demonstration that SEBAL data could be used operationally. The process of moving from Phase I through Phase III has been a logical and linear movement.

2.3 Objectives for Phase III

Phase III had seven primary objectives: 1) relate crop yield to ET; 2) enhancement of the SEBAL web site; 3) development of SEBAL training materials; 4) testing of SEBAL as a regulatory tool; 5) evaluate SEBAL ET as a component of the lower Boise Valley ground water model; 6) complete the year 2000 ET map for southern Idaho; 7) transfer SEBAL technology to Idaho State University.

3.0 User Community

The user community for the Idaho Informart is primarily the Idaho Department of Water Resources, although other water organizations are potential users. Among the other organizations are the U.S. Bureau of Reclamation (USBR), which has cooperated with IDWR in funding SEBAL projects, and other, generally grassroots, water organizations such as canal companies, irrigation districts, and other water measurement organizations.

Of the IDWR groups considering SEBAL-derived ET, the hydrologic modelers are the most comfortable with SEBAL-derived ET, in particular the seasonal ET data for the Eastern Snake River Plain. They have accepted its validity and utility, and are prepared to use it operationally. Two reasons drive the hydrologists' acceptance of SEBAL: first, they are the most familiar with methods of ET calculation, being the group within IDWR that is responsible for ET; and second, the 30-meter pixel size of the Landsat TM SEBAL offers a significant improvement in ET accuracy. Before SEBAL, ET had to be computed on a county-basis due to the nature of the available data. Whole-county ET estimates ware then disaggregated to the 1 km cell-size of the Eastern Snake River Plain Aquifer (ESRPA) ground water model. Estimating ET on the basis of the 900 square-meter Landsat pixel allows aggregation upward to the one- square km model cell, which is potentially a much more accurate estimate. Other IDWR business processes that have become comfortable with SEBAL are the Water Measurement Section, the Snake River Basin Adjudication, and the Water Allocation Section.

Idaho has other water-related organizations that are potentially part of the user community. Some of these organizations are local water delivery organizations, such as canal companies and irrigations districts, water districts, ground water districts, and water users' groups.

Larger, federal agencies are also potential members. The U. S. Bureau of Reclamation has wide ranging responsibilities for irrigation projects throughout the western U.S.

4.0 New Product Development

4.1 Introduction

The emphasis on new products has been web-based. IDWR and UI will work together to modify the SEBAL model to output data from intermediate computations that can be useful to farmers in analyzing their productivity by comparing 1) characteristics of their fields (e.g. ET and vegetation index) to other fields of the same crop, and 2) their own operations from year-to-year. There will be no yield data presented on the web, but a farmer will be able to examine his own, private yield figures for a field and compare SEBAL-computed characteristics to other fields. These intermediate outputs are available by water-right polygon. A farmer can compare these variables in relation to his yield figures, and begin to make any necessary adjustments in his farming practices.

4.2 Yield functions

Yield functions were assembled for Idaho crops from literature to help farmers evaluate relative yield losses stemming from ET stresses as reflected in these intermediate SEBAL variables. UI personnel processed through SEBAL two of the Landsat scenes processed by the University of North Dakota for the North Dakota Synergy Phase II project. UI and University of North Dakota personnel have agreed to collaborate on investigating the utility of integrating SEBAL ET into yield analysis.

In many situations, crop yield and total water consumption are directly related. Photosynthesis and plant yield is maximum when stomates are wide open and the flow of carbon dioxide into leaves is uninhibited. When plants can not extract enough water from soil to keep hydrated, their stomates partially or completely close and evapotranspiration (ET) and photosynthesis are reduced.

Relative yield ($Y_{relative}$) is the ratio of actual yield to maximum yield. Maximum yield ($Y_{maximum}$) is defined as the yield that would be obtained under perfect management and irrigation conditions. Actual yield (Y_{actual}) is the yield actually obtained from the field or subfield area. Therefore, a value of $Y_{relative}$ = 0.9 means that the field or subfield yield is only 90% as much as the potential value.

Table 1. Lookup table for determining Percent Relative Yield from Percent Relative Evapotranspiration.

	% Relative Yield									
% Relative ET	Alfalfa	Beans	Corn	Onions	Pasture	Peas	Potatoes	Spring Grain	Sugar Beets	Winter Grain
100	100	100	100	100	100	100	100	100	100	100
95	95	94	94	95	95	94	95	94	95	95
90	89	89	88	89	89	89	89	89	90	90
85	84	83	81	84	84	83	84	83	85	84
80	78	77	75	78	78	77	78	77	80	79
75	73	71	69	73	73	71	73	71	75	74
70	67	66	63	67	67	66	67	66	70	69
60	56	54	50	56	56	54	56	54	60	58
50	45	43	38	45	45	43	45	43	50	48
40	34	31	25	34	34	31	34	31	40	37
30	23	20	13	23	23	20	23	20	30	27
20	12	8	0	12	12	8	12	8	20	16

This information is on the web as part of the SEBAL site.

4.3 Web Development

Web development took place in two areas: 1) augmenting ArcIMS applications to include a tool to clip and download data, and 2) adding ET queryable by polygon. The work proceeded in these directions to enable the public to be able to access ET data.

The web modifications were designed to enable the public to access the actual ET data in image format. Since the SEBAL data are in very large data sets, it was determined that kind of access to data required allowing the public to clip out a small area of interest and download the clipped image and ancillary vector data.

The compliment to accessing ET data in image form is accessing ET data summarized by polygon. Making ET data available by polygon gives individual irrigators access to the ET for their operations. In order to allow that type of access, it was necessary to develop ET by various types of polygons.

4.4 Training

4.4.1 Introduction

There are two levels of training involved in SEBAL, each requiring different types of training materials, expert level training and introductory training. Training materials have been created for each group.

4.4.2 Introductory SEBAL Training

Basic users of ET maps and products from SEBAL include personnel from federal, state, and local government agencies, farmers, ranchers, and personnel from local water-user organizations who might be regulated by or impacted by application of ET maps and information stemming from SEBAL application and who would be supporters and funders of a SEBAL-based process. These users do not need to know the specific features of SEBAL, but only a general sense of its workings and limitations.

4.4.3 Expert SEBAL Training

4.4.3.1 Introduction

Expert users of SEBAL are professionals who are well educated or trained in remote sensing, evaporation physics, and energy balance theory and application. They are trained to identify various caveats in application of SEBAL to remote images and to make all necessary adjustments to the model to provide the best ET results. This is the highest level of training and will have the smallest audience, albeit a very important audience, for sustained support and application of SEBAL.

Expert training was conducted for the Surface Energy Balance Algorithm for Land (SEBAL) on August 19-23 at Idaho State University. The course was attended by 17 individuals representing Idaho State Government, the Federal Government, Universities in Idaho, Utah, and New Mexico, and the private sector.

4.4.3.2 Instructors

The course was taught by an international team of instructors: Dr. Richard G. Allen, Dr. Wim Bastiaanssen, and Mr. Ralf Waters. Dr. Allen is research professor at the University of Idaho, Kimberly Research Center. His specialty field is evapotranspiration. Dr. Bastiaanssen is a Professor at the International Water Management Institute in Wageningen, The Netherlands and the Scientific Director of WaterWatch. Dr. Bastiaanssen is the originator of SEBAL. Mr. Waters is a principal in Waters Consulting of Nelson B.C., Canada, and a specialist in fluid mechanics. The instructors were assisted by Mr. William J. Kramber, Senior Remote Sensing Analyst at the Idaho Department of Water Resources, and Mr. Masahiro Tasumi, PhD. candidate at the University of Idaho.

4.4.3.3 Expert Training Outline

1. Overview of SEBAL
2. Overview of the theory
3. Setting up the image
4. Obtaining header file information
5. Obtaining weather data, reference ET, and exploring the time issues around these quantities.
6. Solving the surface radiation balance equation:
7. Theory behind using “anchor” pixels
8. Selecting the “cold” pixel
9. Selecting the “hot” pixel

10. Computing incoming longwave radiation
11. Computing the net surface radiation
12. Solving the surface energy budget equation - computing G/Rn and G
13. Theory behind the method of computing sensible heat flux (temperature difference, wind speed, surface roughness, aerodynamic resistance to heat transport)
14. Computation of friction velocity and wind speed at 200 meters for the weather station
15. Computation of the momentum roughness length – land use map
16. Computation of initial friction velocity and aerodynamic resistance for each pixel
17. Theory of the linear dT function and of the atmospheric stability correction
18. Iteration process to compute sensible heat flux – use of the spreadsheet
19. Computation of instantaneous ET
20. Computation of 24-hour ET
21. Computation of seasonal ET
22. Mountain Model

4.5 SEBAL as an Operational Tool

4.5.1 Introduction

In November 2001, the Idaho Attorney General submitted a brief in support of motion for order of interim administration to the 5th Judicial Court. The introduction to the brief states: "The purpose for seeking interim administration is to permit immediate administration of water rights...and to enable the Director [of IDWR] and participating water right holders to take further steps toward long-term administration of the resource." The Brief is in support of a legal process to set-up Water Districts, which have historically regulated and managed surface water, that would now regulate and manage ground water. Within those new ground water districts, water masters will have specific duties, among which will be "to (1) curtail illegal diversions (i.e. any diversion without a water right or in excess of the elements or conditions of a water right); (2) measure and report the diversions under water rights".

IDWR presently has the technical means to identify diversions not having a water right. IDWR has tested and implemented a methodology to accomplish this using water right place-of-use polygons and Landsat TM false-color composite data in GIS. The technical means to identify someone using water "in excess of the elements or conditions of a water right" is more problematic. Nevertheless, IDWR water managers believe that SEBAL may offer a cost-effective solution.

The results of Synergy Phase I and Phase II have convinced IDWR water managers that SEBAL can reliably and accurately derive ET. IDWR tested SEBAL as an operational regulatory tool for administering water rights to identify those fields onto which water was applied in violation of some aspect of the water right. The test covered part of the Eastern Snake River Plain, an area in Landsat path-row 39/30. The specific test was a comparison of righted pumpage rates with ET for water-right places-of-use during the period of peak water demand in July. The comparison was done for 426 water rights in the study area and required comparing the righted pumpage rate and the minimum possible rate given the volume of ET from each associated water right place of use.

4.5.2 Results

UI/Kimberly personnel processed two July 2002 Landsat scenes (July 12 and July 28) for water-right analysis, and delivered maps of cumulative evapotranspiration (ET) for the 17-day period to IDWR 11 days after the second overpass date. Delivery time was well within the IDWR-defined goal of delivery within 14 days of the last overpass.

IDWR water rights and GIS personnel immediately began comparing the SEBAL ET data with water rights. The polygons were selected for the purpose of finding locations where comparisons between water consumption and authorized quantities would be straightforward. They should be based on a single water right without any combined use limits or overlaps.

SEBAL was used to determine cumulative ET for the period between the two images. The ET was compared with the volume of water authorized to be diverted based on valid water rights. Authorized diversion volume was calculated based on the allocated rate of flow continuously diverted over the 17-day period. The comparison results are presented in Figure 2 where water right volume is plotted on the vertical axis and consumption on the horizontal axis. The points lying below the diagonal line indicate consumption exceeding authorized diversions. The line of points along 206 mm of *Water Right* (y-axis) indicates Idaho's standard duty of water, which is 0.02 cubic feet per second (cfs) per acre computed based on the following equation:

$$\frac{206\,mm * 1\,acre}{17\,days} * \frac{1\,ft}{304.8\ mm} * \frac{43{,}560\ ft^2}{1\,acre} * \frac{1\,day}{86{,}400\ \mathrm{sec}} = 0.02\,cfs$$

Points below 206 mm have authorized diversion rates below 0.02 cfs per acre, and are assumed to be within the water right. The maximum water consumption for the investigated period is 122 mm, equivalent to 0.013 cfs per acre.

The comparison quickly highlighted shortcomings in the IDWR water-right data-model that hampered the analysis. A total of 514 polygons were initially selected. Of these, 83 had combined use limits and were not used for this comparison or included in Figure 2. Some 426 water rights in IDWR Basin 35 could be compared with SEBAL-generated ET, and 18 of those were found to have ET greater than the water right could provide. Those 18 positives were handed-off to water-rights personnel for further research.

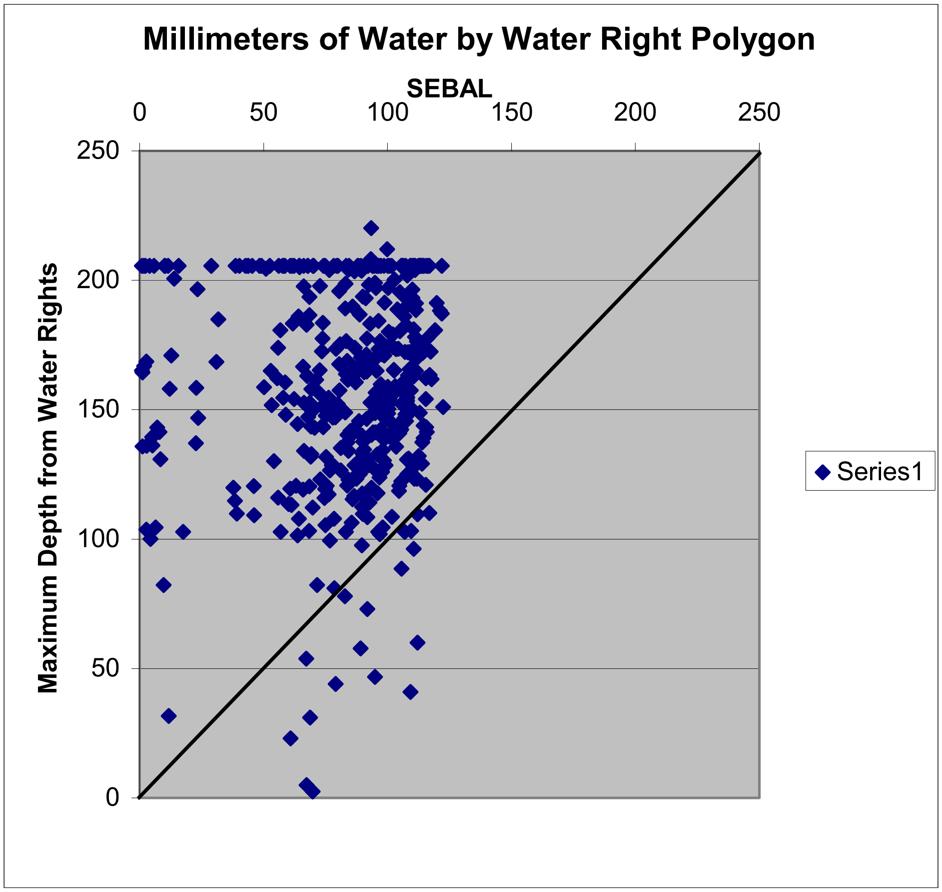

Figure 2. Comparison of cumulative SEBAL ET with maximum water-right ET for 426 water right polygons in Idaho Department of Water Resources Basin 35 for July 12-July 28, 2002 period

IDWR personnel researched the water rights for each of the 18 positives and found that the comparison yielded a false result for fifteen of the eighteen positives, usually (11 records) because the shape-file was selected from the water rights database when the shape-file should have been selected from the adjudication recommendation database.

Three of the eighteen comparisons appear to be valid and the amount of water consumption exceeds the authorized amount. One other record had a comparison based on an incorrect shape, but the shape was similar enough to the correct shape so that the comparison is probably close.

In three of these four cases, the IDWR Water Measurement Information System database indicates that recent flow measurements support SEBAL findings with measured diversion exceeding authorized rates by 18 to 75 percent. In the fourth case, the wells used to irrigate the selected place of use also supply water to other rights and places of use, and when reviewed based on the total combined authorized diversion rate, the actual diversion only slightly exceeds the authorized amount. The identified place of use has a very low authorized application rate (1.8 cfs for 320 acres = 0.0056 cfs/acre). Therefore, SEBAL review identified an excessive diversion that likely would not have been discovered by in-field flow rate measurements.

The enforcement process using SEBAL offers at least two significant improvements over the present method that uses power records. First, SEBAL data can be processed for analysis during the irrigation season, which will allow enforcement actions to be brought in a timely manner. Analysis of power meter records generally cannot be accomplished during the irrigation season due to the reporting protocols and restrictions on personnel time. Second, SEBAL analysis provides the means of identifying some violations that would not be caught by the power-meter method.

4.5.3 User Recommendations

1) Effort should be directed toward improving the selection of water right shapefiles in order to improve comparisons where multiple rights are either coincident or overlapping. Since the upper limit of water consumption for this investigation (0.013 cfs/acre) is well below the Department's standard of 0.02 cfs/acre, identifying farms with diversion rates significantly below this standard value may help focus investigations into potential excessive diversions.

2) SEBAL estimates of water consumption appear accurate and consistent. The Department should consider continued use of SEBAL in future years for determining total annual water consumption and in identifying excessive irrigation diversions.

3) The Department should take enforcement action on the four identified excessive diversions.

4) Consider investigating additional places of use that are near the threshold diagonal line in Figure 2. It is likely that other rights near to, but above, the diagonal line have average diversions that exceed authorized limits. Since losses, which typically account for 10 percent or more of total diversion, are not included in the determination of consumption, actual diversions are expected to exceed consumption to some extent.

4.6 SEBAL ET Layer for Hydrologic Modeling

This project was funded in large part by the U.S. Bureau of Reclamation. It is designed to replace a generalized ET layer created by assigning nominal ET coefficients to polygons of land-cover from a 1994 land cover classification of the Lower Boise Valley. Using SEBAL will offer three advantages over the present ET data: 1) the ET will be for 1997, the date of the other components of the water balance; 2) actual ET will be used rather than ET generated by coefficients; and 3) ET will be computed by 30-meter cell, which can be aggregated up to the model cell size, which should result in a more accurate ET figure.

4.7 Year 2000 ET Map of Southern Idaho

This project was funded largely by the U.S. Bureau of Reclamation. The Bureau has irrigation projects throughout southern Idaho. SEBAL-derived ET allows a more precise estimate of water use than does any previously-available method. USBR is willing to fund SEBAL processing to complete the year 2000 ET map for southern Idaho as a management tool.

4.8 Transfer of SEBAL to Idaho State University

Idaho State University (ISU) now has access to SEBAL. Ten ISU faculty and graduate students completed the SEBAL expert training in August, 2002. An ISU graduate student has successfully ported SEBAL to the IDRISI remote sensing package, which is running at the ISU GIS and remote sensing lab.

5.0 Web Development

5.1 Augmentation of ArcIMS Application

The existing Synergy web site was augmented to include a new ArcIMS application tailored for the year 2000 data on the Eastern Snake River Plain. The new ArcIMS app was developed in three stages.

Stage 1 added basic data consisting of a single mosaic of false-color composite of TM data for the entire six-scene area, and cumulative ET data. The specific TM scenes used were chosen to best represent actively growing vegetation. The TM mosaic was converted to MrSid format for efficient storage and fast retrieval. The cumulative ET image was created by mosaicking the six cumulative ET images and tiling the resulting mosaic into files that match the USGS 1:100,000-scale quadrangles. The 1:100,000-scale files are in GIF format.

Stage 2 saw the development of the means to clip and download the ET and TM images for a polygon or rectangular area chosen from the above themes. The clip-and-download tool is built into the Eastern Snake Plain Aquifer ArcIMS application, and is also available for download. If the tool is downloaded, it can be incorporated into existing ArcIMS applications.

The clip and download tool provides the components and instructions necessary to enable an application to do the following:

1. create a pop-up menu allowing the user to select the layers to download;
2. clip the shape-files and the images for the selected region;
3. put all of the clipped layers in a zip-file;
4. deliver the zip-file to the user.

The image-clipping tool does not deliver a clipped image that is the same size as the screen image. Rather, the tool determines the dimensions of the clipped image from the map coordinates of the region chosen by the user, and delivers the clipped image at the full, original resolution. The number of map-units per pixel (e.g. pixel size in meters) must be specified for each image layer in ArcIMSparam.js script.

The clipped and downloaded image will be of the type delivered by the map service: either a JPG, a GIF, or a PNG. Therefore, it may be slightly degraded if the original image is a TIF. The ArcIMS extract server is used to clip and extract the non-image layers. Any combination of shapes and images may be requested at one time.

The download software uses two active server pages to monitor the production of the images and zip-file. The download will not work under Unix unless the Internet server can process active server pages, which requires a proprietary software package.

Stage 3 added the capability to select a single polygon from a thematic layer and 1) inspect the polygon displayed on SEBAL-derived data, and 2) calculate the following statistics for each of the first three of these products:

- Mean value
- Standard deviation
- Number of pixels in the polygon
- Sum total for the polygon

The thematic polygons included are as follows:

- Irrigation Districts and Canal Companies
- Ground Water Measurement Districts
- Ground Water Management Areas
- Critical Ground Water Management Areas
- Eastern Snake River Plain Aquifer boundary
- Water Right Places of Use
- Counties

The statistics are created by pre-processing the ET image in ArcGIS and storing pixel-count, mean, standard deviation and total acreage for each polygon in the attributes for the layer.

All three stages of development were completed as planned. In addition, the ArcIMS code that allows users to clip and download data was extracted and bundled with explicit directions in a ZIP file. The ZIP file, itself, is available on the IDWR/GIS web site (http://www.idwr.state.id.us/gisdata) for download. Anyone running ArcIMS can incorporate this code into an existing ArcIMS application to enable clipping and downloading.

5.2 Web Statistics

Communication of SEBAL data and information is a critical aspect of the project. The part of the IDWR web site that deals with the Synergy project is summarized in Table 2. The time frames are inconsistent due to the way IDWR tracks Internet activity.

Web Page	site visits	Session Downloads	Period
http://www.idwr.state.id.us/gisdata/ET/final_sebal_page.htm	1,158		4/1/01-10/31/01
Eastern Snake Plain IMS Application	376		1/2/02-11/01/02
http://www.idwr.state.id.us/gisdata/ET/Final+Report.pdf		917	12/31/00-11/01/02
http://www.idwr.state.id.us/gisdata/ET/phase_2_final_report.pdf		191	1/2/02-11/01/02

Table 2. Web site activity.

6.0 Experience of the User Community

6.1 Introduction

The primary user is the Idaho Department of Water Resources. This Synergy project is different from other projects in that the user is also the project manager. This project structure allows the user, IDWR, to find a research organization and to manage that organization's functions to address explicitly problem that IDWR is trying to solve.

6.2 How Users Used the Data

IDWR has begun the transition to making SEBAL-derived ET operational in both its internal programs and with cooperative projects with other government agencies. Internally, IDWR requested and the Idaho Legislature appropriated $54,000 for research, coincident with Phase II, into the use of SEBAL as an input to the Eastern Snake River Plain aquifer model, IDWR is prepared to commit significantly more monetary resources coincident with Phase III in support of testing SEBAL as an operational, regulatory tool.

Externally, also coincident with Phase III, IDWR and the U.S. Bureau of Reclamation are cooperating to use SEBAL to generate the ET component of the water budget for the Lower Boise Valley ground water model.

IDWR has drafted the "Outline for Creation of Water Districts and Administration of Rights to the Use of Ground Water From the Eastern Snake Plain Aquifer in IDWR Administrative Basins 35, 36, 41, and 43", which is dated Dec. 10, 2001. Attachment B to that outline is a set of instructions to district watermasters. In Section 1-j of those instructions, watermasters are directed to " Monitor water use in the district in accordance with the approved annual work plan, including obtaining and reporting the data necessary for SEBAL computations."

6.2.1 Test of SEBAL as an Operational Regulatory Tool

6.2.1.1 Description

IDWR presently has the technical means to identify diversions not having a water right. IDWR has tested and implemented a methodology to accomplish this using water right place-of-use polygons and Landsat TM false-color composite data in GIS. The technical means to identify someone using water "in excess of the elements or conditions of a water right" is more problematic. Nevertheless, IDWR water managers believe that SEBAL may offer a cost-effective solution.

The results of Synergy Phase I and Phase II have convinced IDWR water managers that SEBAL can reliably and accurately derive ET. IDWR proposes testing SEBAL as an operational regulatory tool for administering water rights in accordance to identify those fields onto which water has been applied in violation of some aspect of the water right. The test will cover part of the Eastern Snake River Plain aquifer, an area in Landsat path-row 39/30. The specific test will be a comparison of righted pumpage rates with ET for water-right places-of-use during the period of peak water demand in August. The comparison will be done for approximately 50 water rights in the study area and will require comparing the righted pumpage rate and the minimum possible rate given the volume of ET from each associated water right place of use. IDWR water-right managers have committed to examine every water right in the IDWR Administrative Basin 35 (approximately 2,200) and to do all necessary maintenance on the POU shape and associated database to support this test.

The two July, 2002 Landsat scenes (July 12 and July 28) for water-right analysis were processed by UI/Kimberly personnel, and maps of cumulative evapotranspiration (ET) for the 17-day period were delivered to IDWR 11 days after the second overpass date. Delivery was well within the IDWR-defined goal of delivery within 14 days of the last overpass. IDWR water-rights and GIS personnel immediately began comparing the ET data with water rights. The comparison quickly highlighted shortcomings in the IDWR water-right data-model that hampered the analysis. The personnel involved are documenting the problems found in water rights, and outlining the methods needed to fix the problems. This documentation will serve as a task outline addressing the issues found. As illustrated by Figure 2, some 426 water rights in IDWR Basin 35 were able to be compared with SEBAL-generated ET, and 18 of those were found to have ET greater than the water right could provide. Those 18 positives were handed-off to water-rights personnel for further research.

6.2.1.2 Policy Impact

The potential policy impact is significant. IDWR has begun to administer ground and surface water conjunctively, and conjunctive administration requires that ground water use be monitored as strictly as is surface water use. There is presently no effective method for monitoring annually all ground water use. The adoption of SEBAL by IDWR and other water measurement organizations will impact policy by allowing consistent, efficient water use measurements for water right administration.

IDWR should consider continued use of SEBAL in future years for determining total annual water consumption and in identifying excessive irrigation diversions.

IDWR should take enforcement action on the four identified excessive diversions. The water right owners should be notified of our findings and be offered an opportunity to operate within the authorized limits of their water right(s). Transfer of additional water rights to the place of use, or permissible place of use transfers combining additional rights, may present acceptable solutions. If needed, the diversions should be carefully monitored during future irrigation seasons in order to ensure satisfactory compliance, which may require installation of flow meters and data loggers.

IDWR may also consider investigating additional places of use that are near the threshold diagonal line in Figure 2. It is likely that other rights near to, but above, the diagonal line have average diversions that exceed authorized limits. Since losses, which typically account for 10 percent or more of total diversion, are not included in the determination of consumption, actual diversions are expected to exceed consumption to some extent.

6.2.1.3 Fiscal Impact

The fiscal impact is that SEBAL can be used to estimate ground water use for less the 10% of the cost of the present method.

IDWR has an active program to measure the pumpage by ground water irrigators on the Eastern Snake River Plain. That work is done by the Water Measurement Section (WMS) at IDWR, which has 3 FTEs that are dedicated to the ground water measurement program. Other IDWR personnel in the Regional Offices also work in this program. Among other tasks, The WMS oversees the installation of flow meters on wells, computes power consumption coefficients on un-metered wells, compiles and stores power meter records on wells, and analyzes power data to compute ground water pumpage. Approximately 5,000 wells are in the program. In each year of the program, IDWR has spent approximately $150,000 to support it. The associated Water Measurement Districts spent about the same amount. Other regulated water users have spent money supporting the program, as well. For all that, the WMS program can afford to monitor only about 1/3 of the wells in any given year.

In Phase II, IDWR ran SEBAL on the Eastern Snake River Plain. If SEBAL is operational, IDWR can cover the Eastern Snake River Plain with 6 Landsat scenes, which will allow us to generate SEBAL-derived ET on a field-by-field basis. The cost for the data (scenes plus terrain correction and map registration) will be just under $24,000. SEBAL processing will require personnel time of about $8,000. An additional $5,000 to $8,000 will be needed to overlay the water right polygons, compute the volume of water lost thru ET, relate that to pumpage, and compare the estimated pumpage to water rights. For approximately $40,000, IDWR can process the entire Snake River Plain, and about 50% more than that for all of Southern Idaho, which is where nearly all the state's irrigation is found.

The use of SEBAL ET will not replace the existing program, per se. Pumpage data that can be related to individual water rights will be needed to check the SEBAL ET, and other methods of monitoring will be needed for fields using a combination of surface and ground water. Even if the Water Management program is maintained at its present level, using SEBAL will result in the availability of good pumpage data for another approximately 5,000 irrigation wells, and for all surface water rights, at a dramatically lower marginal cost.

6.2.2 Lower Boise River Valley Water Budget

6.2.2.1 Description

Since 1996, IDWR has led a $2.5 million, multi-agency (state and federal) project to study the water resources of the Lower Boise Valley. This area is receiving significant attention because of rapid population growth in the valley. One of the major efforts of the project is construction of a groundwater model of the valley. The U.S. Bureau of Reclamation has spent the last three years studying irrigation diversions from the Boise River and irrigation return flow into the river in order to better quantify the water balance for the model. The third main component of the water balance is ET. IDWR and USBR have recently agreed to cooperate on a project to compute the ET portion of the water balance using SEBAL. The base year for the water balance is 1996.

A preliminary comparison was made using results from the SEBAL ET analysis (1997 data) and the ET used in the 1996 Water Budget. The comparison was made with ET for flood-irrigated lands only as this was the land type that was examined in the water budget. This preliminary comparison was made using three model cells within the Treasure Valley Hydrologic Project ground water model domain; the selected cells were identified as being the three cells having the greatest flood-irrigated acreage. Each model cell is one square mile in area (640 acres).

Table 3 summarizes the data used in this initial comparison. The weighted average ET used in the 1996 Water Budget was 2.42 feet. This value was based upon 11 crop types, and the average ET for the years 1988-1994 (Parma Field Station).

MODEL ROW	MODEL COLUMN	FLOOD ACRES	WATER BUDGET ET (feet)	SEBAL ET (1997) (feet)
				Apr. 15 to Oct. 15
10	17	631	2.42	2.40
11	18	623	2.42	2.69
28	25	622	2.42	2.17
			AVERAGE SEBAL ET:	2.42

Table 3. Comparison of ET methods

Typically, the canal system within the Boise Valley is operational during the April 15 to October 15 time period: this is generally considered to be the flood irrigation season, and also the main period of crop growth. Prior to April, temperatures are generally too cold for most crops. As shown in Table 3, SEBAL ET ranged from 2.17 feet to 2.69 feet during the irrigation season; the average ET for these three cells is 2.42 feet, which is compared to the 2.42 feet used in the 1996 Water Budget.

The ET used in the 1996 Water Budget was developed from the 1988 to 1994 period. The average precipitation at Parma for the years 1988-1994 was 7.56 inches, whereas the precipitation for the year 1997 (SEBAL ET period) was 10.59 inches (USBR Agrimet data). Given these data, the similarity in the two ET estimates is not a function of precipitation alone, and further investigation will be required, such as examining more closely the changes in crop types from within a random selection of model cells, etc.

The correspondence between the two ET values is striking, and invites further study. Nevertheless, the correspondence in no way diminishes the potential utility of SEBAL ET as a component of a water budget. The present coefficient-based method assumes ET is constant throughout the entire Treasure Valley, regardless of known changes in total precipitation, temperature, etc. The method also assumes the same average ET for all crop types. This approach works well enough for a valley-wide water budget that sums total inflows and outflows. However, the water budget is also generated on a cell-by-cell basis, with the result used as input to the regional ground water model (square mile grid size).

The model is very sensitive to changes in recharge, which is a function of ET. Since we know ET is not actually constant throughout the model domain, the ability to refine the ET spatially with SEBAL will result in a calibrated ground water model that more closely reflects actual conditions. This refinement is even more important as IDWR begins using smaller grid sizes (e.g., 1/4 mile) to create sub-models of smaller areas of the valley.

6.2.2.2 Policy Impact

The major impact this experience will have will be in the method by which ET is generated for use in IDWR ground water modeling. Impacts will come later in applying the results of the model. The modeling being done now will impact future water development in the Lower Boise Valley.

6.2.3 Complete Year 2000 ET Map of Southern Idaho

6.2.3.1 Description

This project is largely funded by the U.S. Bureau of Reclamation. The Bureau has irrigation projects throughout southern Idaho. SEBAL-derived ET allows a more precise estimate of water use than does any previously-available method. USBR is willing to fund SEBAL processing to complete the year 2000 ET map for southern Idaho as a management tool.

This product has received more attention than anticipated, and is an excellent example of synergy. The U.S. Bureau of Reclamation and IDWR previously cooperated to generate a land-use/land-cover (LULC) classification of the Boise Valley for the year 2000 from 1:12,000-scale aerial photography. The classification consists of twenty-four LULC classes in a digital format. The project required an assessment of irrigated agriculture, so the LULC classes needed were only two: irrigated and non-irrigated. IDWR remote sensing and GIS personnel decided to spend time and more money on the project by expanding the number of classes from two to twenty-two, each of which has a detailed description.

The availability of detailed LULC classes has enabled IDWR to combine the LULC classification with the SEBAL ET data to generate preliminary values for ET by land cover class, data that were not previously available. Preliminary values for ET by LULC class are summarized in Table 4. These values are considered preliminary because SEBAL parameters for aerodynamic roughness are designed for agricultural canopies rather than for non-agricultural surfaces.

IDWR is responsible for comprehensive river basin planning in Idaho. Coincident with Phase III, IDWR is developing a plan for the lower Boise River Basin. One of the important issues the planners are contending with is the potential for water availability in a valley that is rapidly changing from agricultural land use to more urban types of land uses. There is a specific and controversial issue: how does water-use by agricultural land use compare to water use by residential land use? This issue relates directly to the availability of water for urban growth over the next 25 to 50 years. IDWR is in a unique position to analyze and answer this question.

This task finishes the year 2000 ET map, generating 24-hour ET maps for seven dates: March 21, April 30, June 1, June 25, July 27, August 28, and October 2. In addition, a cumulative, or seasonal total, ET map was generated for the period March 15 to October 15.

Class Name	Class Number	Number of Pixels	Area in Acres	Seasonal ET in MM	Seasonal ET in Inches	Standard Deviation in MM
Wetland	5	65,133	14,485	1,025	40.4	285
Water	4	59,387	13,207	924	36.4	165
Recreation	17	22,867	5,085	826	32.5	252
Perennial	22	30,132	6,701	820	32.3	212
Irrigated Crops	21	1,567,500	348,603	812	32.0	189
Canal	7	12,342	2,745	731	28.8	203
Urban Residential	12	45,846	10,196	684	26.9	157
Rural Residential	14	112,938	25,117	657	25.9	192
Farmstead	11	24,927	5,544	609	24.0	188
New Subdivision	13	127,967	28,459	606	23.9	146
Sewage	19	2,582	574	552	21.7	256
Public	16	23,558	5,239	548	21.6	263
Other Ag	28	31,699	7,050	536	21.1	243
Dairy	26	6,716	1,494	524	20.6	182
Feedlot	25	18,793	4,179	479	18.8	205
Junk Yard	81	1,440	320	467	18.4	193
Abandoned Agriculture	27	20,412	4,540	459	18.1	211
Transition	24	30,136	6,702	437	17.2	195
Idle Agriculture	23	33,800	7,517	436	17.2	215
Transportation	18	25,704	5,716	420	16.5	222
Commercial and Industrial	15	64,029	14,240	380	15.0	196
Barren	6	21,257	4,727	335	13.2	258
Unclassified	99	141,583	31,487	298	11.7	239
Rangeland	3	1,007,201	223,995	242	9.5	160
Petroleum Tanks	82	201	45	237	9.3	112

Table 4. Preliminary values for evapotranspiration by land use/land cover class in the lower Boise Valley, Idaho.

6.2.3.2 Policy Impact

This product has potentially a very large impact. The IDWR Planning Bureau has two projects that are using SEBAL data unexpectedly: 1) the 50-year analysis of water availability in the Boise Valley, and 2) a program to secure water from tributary watersheds in the upper Salmon River Basin. The Boise Valley study was able to use SEBAL ET for a preliminary comparison of water use by residential versus agricultural land. In the Salmon Basin, SEBAL ET will be used both for modeling water use and for monitoring compliance with irrigation curtailment.

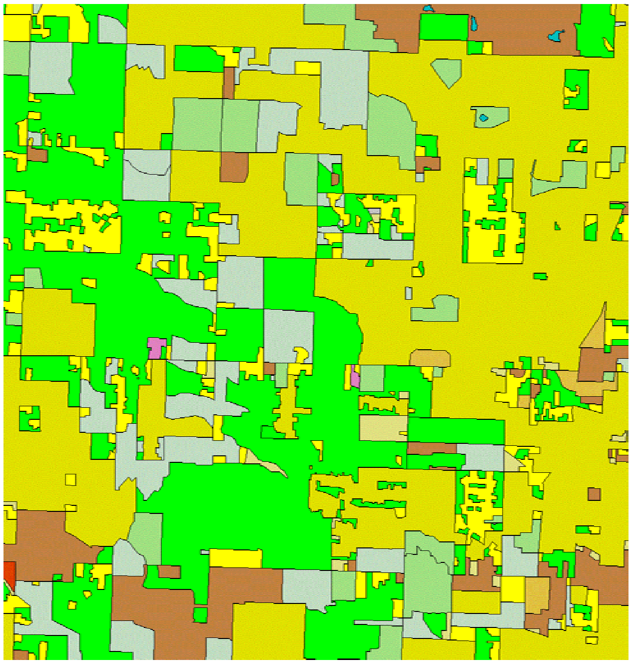

Figure 3. Landuse/land cover in the Boise Valley.

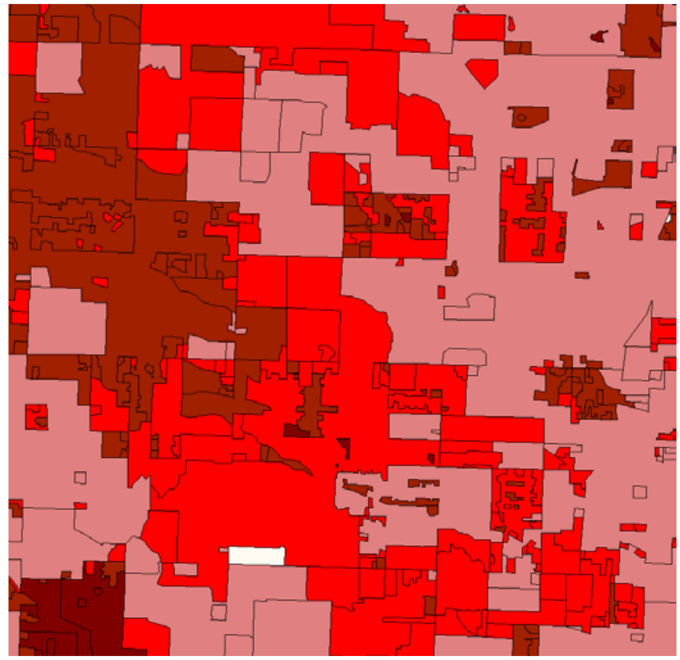

Figure 4. Color-coded map showing the 24-hour ET for the area polygons of Figure 3.

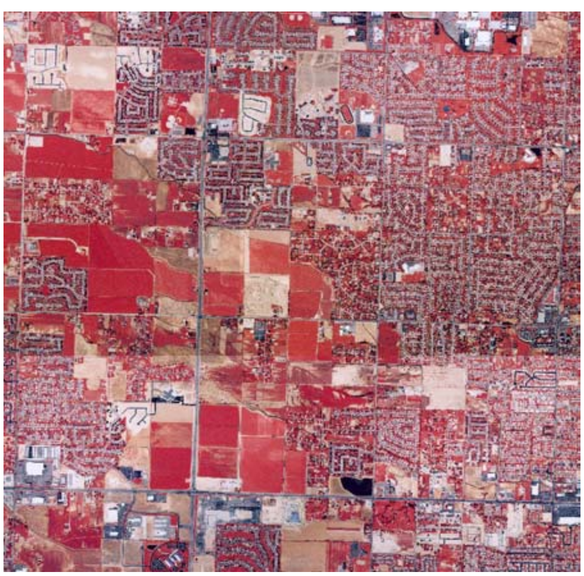

Figure 5. Aerial photograph of the area covered by Figure 3.

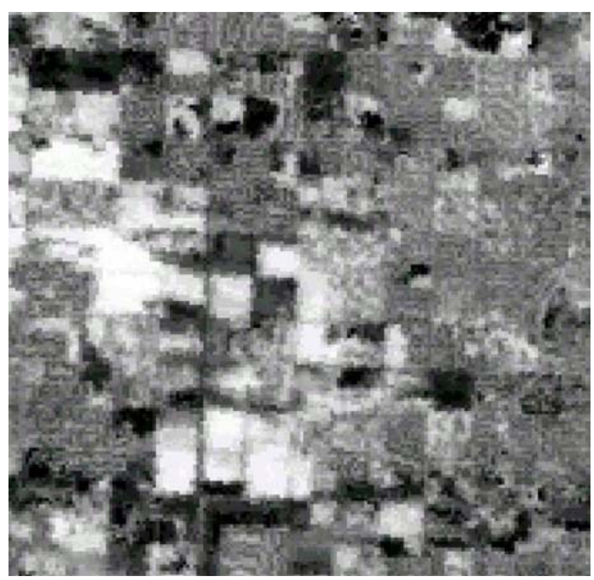

Figure 6. Pixel-by-pixel ET data for the area covered by Figure 3. Black is lower ET, white is higher ET.

The IDWR and the USBR are finding that they have cooperative projects that are well-suited for SEBAL. The watershed-modeling project in the Lemhi Basin has begun to use SEBAL ET. The second year of the High-Lift pump project, which is in the planning stage, will use SEBAL to assess the reduction in water use by the project participants. Since the participants are being paid to reduce their water use, quantifying the reduction in water use is critical to the integrity of the project.

The analysis of ET by land use/land cover type has the potential to significantly affect policy. IDWR planners are working on a 50-year time horizon for water-supply issues. Competing water interests advocate different positions about the effect of converting irrigated agriculture to residential land. SEBAL data coupled with the land use/land cover polygons, developed in cooperation with the U.S. Bureau of Reclamation, offer the first quantitative data on which an analysis can be based.

The significance of having quantitative data on ET by land use/land cover type is illustrated by the following quote from the September 20, 2002 issue of Capital Press (www.capitalpress.com), a northwest agricultural weekly newspaper:

“Some irrigation districts that have traditionally delivered water only for crops have gradually shifted more of their operations toward pressurized irrigation systems for homeowners as more farmland has been converted to subdivisions.

”But that hasn’t meant a reduction in total water usage, said Dan Steenson, an attorney who represents the Nampa-Meridian Irrigation District in the Boise Valley.

”Many homeowners like to keep their lawns green as long as possible and their water usage extends beyond the normal crop-growing season.

“There actually hasn’t been the kind of dropoff you might expect when ag lands are covered with streets and roof tops,” Steenson said. With the rapidly growing population in the Boise Valley, conflicts between the irrigation district — which manages an extensive system of open canals, ditches, drainages — and homeowners and municipalities has also increased, Steenson said.”

6.2.4 Transfer SEBAL Technology to Idaho State University

6.2.4.1 Description

Idaho State University (ISU) ISU has a remote sensing and GIS program in its Geosciences Department, and has the personnel, software and hardware infrastructure necessary to support SEBAL. ISU also works extensively with the U.S. Department of Energy’s Idaho National Engineering and Environmental Laboratory (INEEL) on hydrologic studies of the INEEL reserve.

The core of the transfer of SEBAL to ISU was the one-week workshop conducted at ISU by Dr. Allen and Dr. Bastiaanssen. The workshop covered the theory and derivation of SEBAL, the potential applications, and the practical considerations in processing satellite data through the SEBAL model. The workshop was attended by 10 ISU faculty and graduate students from the Geosciences Department.

6.2.5 Develop Training Materials

6.2.5.1 Description

Materials to support both introductory training and expert training are complete. Introductory training has not yet been presented. Expert training was conducted at Idaho State University during the week of August 19, 2002.at the GIS Training and Research Center at ISU. Seventeen attendees, including 10 ISU faculty and graduate students learned the theory and application of SEBAL.

Figure 7. Rick Allen in front of the class.

Figure 9. Rick Allen illustrates eddy diffusivity with bubbles

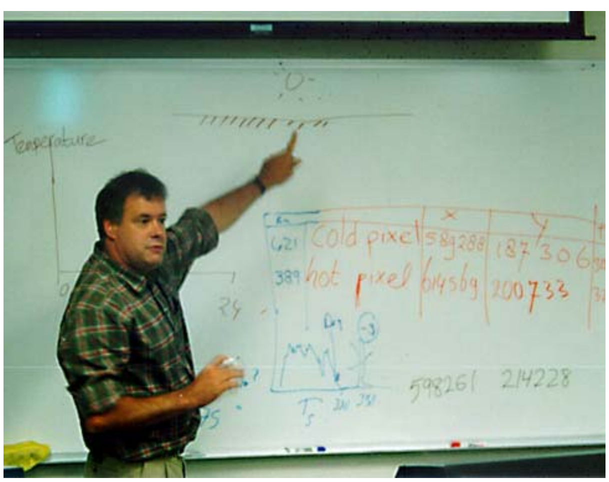

Figure 8. Wim Bastiaanssen discussing what makes good anchor pixels.

Figure 10. Student participation.

The students were given an evaluation form that is fully summarized in Section 14.0, Appendix D. The average numerical rating for the overall quality of the training was 8.9 on a scale of 1 (poor) to 10 (outstanding).

7.0 Lessons Learned

7.1 Incorporating New Technology

In trying to implement a new technology as an operational tool, the new technology may work fine, but the old and well-used components may not work well with the new technology. This is illustrated by the fact that IDWR was able to get SEBAL ET data within its designated time-frame, but the analysis of ET by water right was hampered by its water right data-model, which is not optimal for such analysis.

7.2 Unexpected Uses

It pays to advertise. Unexpected uses for a data set can turn out to be extremely important. The IDWR planners found ET by land use/land cover class to be a product they had a critical need for. The Community Planning Agency for Southwest Idaho regards the same product as invaluable, and requested it for use in their planning programs.

8.0 Requested Equipment

Three hardware items were purchased with Phase III funds. A Dell Latitude C610 Notebook Computer ($3,000) and an InFocus LP 130 projector ($3,900) were purchased to present workshop and briefing materials to other potential users and to cooperators.

A Dell PowerValt 211S external storage array ($6,000) was purchased to support the large volume of data to be served from the ArcIMS applications on the web server. The volume of image data generated and to be served in the Informart is as follows:

Phase I	4.4 GB
Phase II	49.3 GB
Phase III	23.4 GB
	77.1 GB

All equipment was received and integrated.

9.0 Synergy with Other Infomarts

UI modified the SEBAL model to output data from intermediate computations that can be useful to farmers in analyzing their productivity by comparing their yields 1) to other fields of the same crop, and 2) to their own operations from year-to-year. There are no yield data presented on the web, but a farmer can examine his own, private yield figures for a field and compare SEBAL-computed characteristics to other fields.

Yield functions were assembled for Idaho crops from literature to help farmers evaluate relative yield losses stemming from ET stresses as reflected in ET. UI personnel reviewed the yield work done by Dr. George Seielstad of the University of North Dakota Synergy Project. The information gleaned from working with North Dakota Synergy personnel was incorporated into the results discussed in Section 4.2.

UND personnel requested that UI personnel process one Landsat scene for Path/row 39/29, July 16, 2002. The image was of Montana, and covered the Gordon Decker ranch. UI provided ET, relative ET, and NDVI images for July 16 and ET and relative ET for the entire month of July.

10.0 Potential Activities for Phase IV

10.1 Introduction

The results of Phase III point the way to making further gains in the technology and application of SEBAL.

10.2 Surface Roughness for Residential Land and Rangeland

The user response to Phase III demonstrated there is a critical need to quantify evaporative water consumption by residential land cover types. The SEBAL model provides valuable means for predicting ET from residential land, but validation is needed to confirm internal components of SEBAL for predicting aerodynamic roughness and ground heat fluxes from non-agricultural land cover types. These components directly affect the amount of ET predicted by SEBAL.

In addition to cities, more improvement is needed to predict consumptive water use by grasses and shrubs in desert regions. This consumption is highly variable in space and time due to the heterogeneous nature of vegetation cover, hydraulic soil properties, ground water table depths, and differences in water availability caused by hydrologic processes. Better understanding of water use patterns and their spatial distribution in natural vegetation systems including desert, rangeland, forest, and riparian systems is critical to better understanding of ET on a watershed basis.

10.3 Refinement in the Year 2000 ET Values for the Boise Valley

The discovery by the IDWR Planners that SEBAL can be used to quantify ET by land cover type has meant that SEBAL is being used as part of the basis for long-range planning, a controversial subject. The ET values now being used by the Planners have two weaknesses that need to be addressed to make them more defensible: 1) the ET values are aggregated by land use/land cover polygons of unknown accuracy, and 2) the surface roughness used in SEBAL is not calibrated for residential land cover types.

10.4 Validation of IDRISI SEBAL Model

The SEBAL model has been ported to IDRISI. Before the IDRISI model is released, it needs to be validated. Validation will be done by running the IDRISI model on a Boise Valley scene that was previously processed by IDWR personnel through the ERDAS version of the SEBAL model. IDWR has all the intermediate output from the ERDAS processing, and has detailed notes on the processing steps. These extensive data will allow each processing step to be compared and to isolate efficiently any discrepancies.

10.5 Establishing SEBAL as an Institutional Water Resource Tool

Phase III was successful in demonstrating that SEBAL can be used operationally in Idaho. The basis for using SEBAL operationally is three-fold: 1) cost, 2) speed, and 3) accuracy. In Phase II IDWR personnel used the year 2000 SEBAL data to compare the cost of using SEBAL to compute water use for individual water rights with the existing method based on power records, and found that SEBAL-computed water use was approximately 94% less than the cost of the existing program. The speed of SEBAL was demonstrated in Phase III, when IDWR personnel completed a comparison of seventeen-day SEBAL-generated ET with water rights within two weeks of the second Landsat overpass. The accuracy of SEBAL was demonstrated when IDWR compared the ET from SEBAL with water use from power records in Phase II.

Demonstration of SEBAL's operational capabilities was a very significant milestone that needs to be followed-up with a concerted effort to build support in the Idaho water user community for the incorporation of SEBAL as an institutional tool for water administration. Support will be built through education of water users with the training materials developed in Phase III, and through continued generation of SEBAL ET data.

11.0 Appendix A: Publications and Presentations

11.1 Publications

Allen, R.G., A. Morse, M. Tasumi, R. Trezza, W. Bastiaanssen, J.L. Wright, and W. Kramber; 2002; Evapotranspiration from a Satellite-Based Surface Energy Balance for the Snake Plain Aquifer in Idaho. Proceedings of the 2002 USCID/EWRI Conference, San Luis Obispo, July 9-12, 2002; p.167-178.

Allen, R.G., W. Bastiaanssen, J.L. Wright, A. Morse, M. Tasumi, and R. Trezza. 2002. Evapotranspiration from Satellite Images for Water Management and Hydrologic Balances; Proceedings of the 2002 ICID Conference, Montreal, Canada, July, 2002. CD-ROM

Morse, A., W.J. Kramber, R.G. Allen, M. Tasumi, R. Trezza, and J.L. Wright; 2002; Deriving Evapotranspiration Directly from Landsat TM Data; Proceedings of the 2002 Summer Specialty Conference, American Water Resources Association; Keystone, CO.

Kramber, W.J, A. Morse, R.G. Allen; 2002; Developing surrogate Pixels for Comparing SEBAL ET with Lysimeter ET Measurements; Proceedings of Symposium 2002, International Geoscience and Remote Sensing Symposium; Toronto, Ontario

Morse, A., W.J. Kramber, R.G. Allen, M. Tasumi, R. Trezza, and J.L. Wright; 2002; Evaluating SEBAL: Can a Landsat-Based Evapotranspiration Model Help Manage Water Rights in Idaho?; Proceedings of the 2002 Spring Meeting; American Geophysical Union; Washington, D.C

Allen, R.G, W. Bastiaanssen, J.L Wright, A. Morse, M. Tasumi, and R. Trezza; 2002; Evapotranspiration from Satellite Images for Water Management and Hydrologic Balances; Proceedings of the 2002 Conference of the International Commission on Irrigation and Drainage; Montreal, Quebec.

Allen, R.G., M. Tasumi, W. Bastiaanssen, W. Kramber, A. Morse, R. Trezza, and J.L. Wright; 2002; Evapotranspiration From Satellite and SEBAL for the Snake Plain Aquifer in Idaho; United States Committee on Irrigation and Drainage Conference on Energy Climate, Environment and Water; San Luis Obispo, CA

Tasumi, M. 2003. Progress in operational estimation of regional evapotranspiration using satellite imagery. Ph.D. dissertation, Dept. Biological and Agricultural Engineering, University of Idaho. 216 p.

Trezza, R. 2002. Evapotranspiration using a satellite-based surface energy balance with standardized ground control. Ph.D. dissertation, Dept. Biological and Irrigation Engineering, Utah State University. 291 p.

11.2 Presentations

Britton, B. and A. Morse; 2002; A clip and Download tool for ArcIMS; presented at the 2002 Northwest GIS User Group Conference; Sunriver, OR

Kramber, W.; 2002; How SEBAL Works; presented to Idaho Department of Water Resources Planning Bureau; Boise, ID

Morse, A; 2002; SEBAL – a Remote Sensing Water Rights Management Tool; presented to Western States Water Council, Water Information Management Systems Workshop; Salem, OR

Morse, A.; 2002; SEBAL Evapotranspiration Project: What Have We Learned and Where Are We Going?; Oregon State University – Malheur County Campus; Ontario, OR

Morse, A.; 2002; SEBAL – An Evapotranspiration Model; presented to University of Washington climate research staff; Boise, ID

12.0 Appendix B: Student Involvement

12.1 Introduction

Synergy Phase III supported graduate students at both Idaho State University and the University of Idaho. The students were at both the MS and Ph.D. levels, both full and part time.

12.2 University of Idaho

Three UI PhD candidates were supported entirely by Synergy. Masahiro Tasumi and Ricardo Trezza both successfully defended SEBAL-related dissertations in November, 2002. Tasumi and Ricardo have worked full-time on SEBAL, Tasumi beginning at the start of Phase I, and Ricardo beginning with Phase II. Maria Gloria Romero was supported for 18 months under Phases II and III.

12.3 Idaho State University

Reuben Snyder, an MS candidate was supported for the academic year 2002-2003 by Synergy. He ported SEBAL from ERDAS to IDRISI and wrote the introductory training materials after taking the SEBAL expert training in August.

13.0 Appendix C: Equipment Inventory

One Dell Latitude notebook computer
One Infocus LP130 projector
One Dell StorageVault with 3 73GB disk drives
One Canon PowerShot S200 digital camera
One Garmin GPS V GPS receiver

14.0 Appendix D: Summary of Student Evaluations for SEBAL Expert Training

Course attendance: 17
Evaluations Received: 14

1. Please list your goal(s) in attending the SEBAL Expert Training:

10	Gain experience in SEBAL
5	Gain experience in ERDAS
2	Learn how SEBAL can be used in ecological applications
1	Evaluate potential research applications of SEBAL
2	Better understand physical processes of ET
1	Evaluate desert/rangeland applications of SEBAL
1	Get experience in applications of remote sensing
1	Explore feasibility of using SEBAL for regional ET estimation
1	Learn about future SEBAL applications
1	Evaluate SEBAL for wildfire risk modeling
1	Evaluate SEBAL for vector-borne diseases

2. Did you achieve your goal(s)?

12	Yes
1	More than expected
1	Need more training

3. The training ran from 1pm on Monday to 12, noon on Friday

Was the length of training appropriate?

11	Yes
1	Too short
1	Too long
1	Could be 4 full days

Would you recommend a different length?

9	No
1	3 days
1	2 weeks
2	Longer if Mountain Model to be fully explored
1	Shorter lunch and later start

Could you afford more time for a longer SEBAL course?

5	Yes
6	No
3	Maybe

4. Was the course sufficiently comprehensive?

14	Yes

5. Would you pare-down the material?

3	Yes
11	No

6. What did you like, and what did you dislike?

Liked:

1 diversity in the trainers
1 theory on ERDAS Modeller
1 quality of instructors
1 hands-on
1 learned a lot
1 great introduction to SEBAL and energy balance
1 well-presented; moved well
1 availability of expert opinion
1 the training materials
1 not a cookbook-style course; theory explained along with algorithms
1 informal, flexible, yet stayed on task and on time
1 team approach to lectures

Disliked:

1 went too fast
1 first 2 days too slow; second two too fast
1 some repetition
1 hard to stay focused by Thursday afternoon
1 use of whiteboard – writing too small, sometimes illegible
1 sidebar conversations among participants were distracting
1 the computers
1 limited disk space on Instructor's PC

7. Would you recommend the training in its present form to colleagues?

14 Yes

8. What do you feel would be a reasonable cost for the training you received?

1 Free for students and professors
3 $100-$200
1 $200-$400
1 $ 250 - $500
2 $300 - $ 400
1 A few hundred dollars
1 $1,000
1 $1,000 - $1,500
1 $1,250
2 ?

9. Did you find the training materials (the manual, the PowerPoint slides, and the CD) adequate for the training?

10 Yes
1 Manual could use more screen grabs
1 Very good, especially the manual and the CD examples

1 Manual and PowerPoint excellent
1 Published SEBAL papers would be useful

10. On a scale of 1 (poor) to 10 (outstanding), how would you rate the training?

10 - 4
9 - 4
8 - 6

11. Do you have any additional comments to add?

> SEBAL community should have a fixed web site for communication.
> A useful discussion would be on SEBAL's application to regions with various geographic features.
> Have the first 4 hours on ERDAS ModelMaker operation.
> Provide printouts of the PowerPoint presentation to take notes on.
> Keep going.
> Include a discussion of errors. This aspect of the subject should have been included. (Included on 3 critique sheets)

15.0 Appendix E: User Analysis of SEBAL as an Operational Tool

MEMORANDUM

To: Dave Tuthill
cc: Tim Luke
Tony Morse
From: Scott King
Date: October 3, 2002

Subject: Recommendations for enforcement review based upon SEBAL crop water evapotranspiration results

This memorandum details an investigation into water consumption on individual farms and compares consumption to authorized diversion amounts. Consumption is based on two LANDSAT satellite images taken during July 2002 using the SEBAL (Surface Energy Balance Algorithm for Land) methodology to determine evapotranspiration (ET). Some farms appear to be consuming more water than rights authorize to be diverted. Recommendations are made for possible enforcement proceedings.

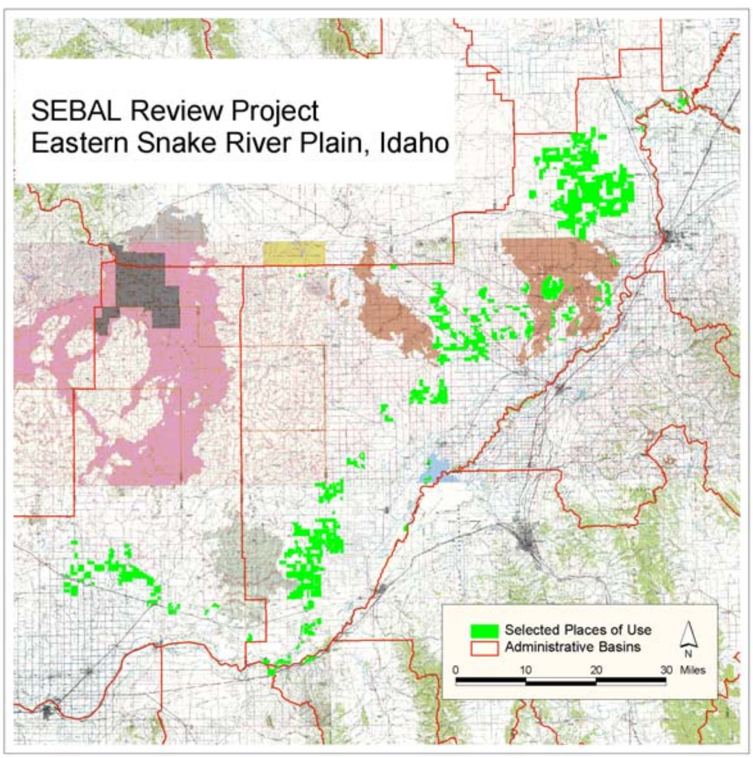

Figure 1. Selected polygons for water consumption determination and comparison.

Study site

The area investigated primarily includes parts of Basins 35 and 36. Michael Ciscell selected place of use polygons based on his document *SEBAL Water Right Data preparation and diversion calculation* where water right irrigation polygons are selected in order to determine water consumption for discrete areas. Figure 1 indicates the location of selected polygons.

Methodology

The polygons were selected for the purpose of finding locations where comparisons between water consumption and authorized quantities would be straightforward. They should be based on a single water right without any combined use limits or overlaps.

SEBAL is used to determine evapotranspiration (ET) based on two LANDSAT images dated July 12 and July 28, 2002. Cumulative ET for the period between images is determined. This volume of water consumed is compared with the volume of water authorized to be diverted based on valid water rights. Authorized diversion volume is calculated based on the allocated rate of flow continuously diverted over the 17-day period. The comparison results are presented in Figure 2 where water right volume is plotted on the vertical axis and consumption on the horizontal axis. The points lying below the diagonal line indicate consumption exceeding authorized diversions. The line of points along 206 mm of *Water Right* (y-axis) indicates Idaho's standard duty of water (0.02 cfs per acre) computed based on equation 1:

$$\frac{206\,mm * 1\,acre}{17\,days} * \frac{1\,ft}{304.8\ mm} * \frac{43{,}560\,ft^2}{1\,acre} * \frac{1\,day}{86{,}400\ \text{sec}} = 0.02\,cfs \qquad (1)$$

Points below 206 mm have authorized diversion rates below 0.02 cfs per acre. The maximum water consumption for the investigated period is 122 mm, equivalent to 0.013 cfs per acre.

A total of 514 polygons were initially selected. Of these, 83 had combined use limits and were not used for this comparison nor included in Figure 2. My task was to investigate the results, determine the validity of the comparison, and answer the following questions: Were the appropriate right(s) selected? Are other rights associated with the place of use that were not identified? Do SEBAL water consumption values appear accurate and consistent? Does the department have records of discharge measurements for the point(s) of diversion supplying water to the place of use, and if so do the measurements support these findings? Are the measured discharges consistent with SEBAL consumption values?

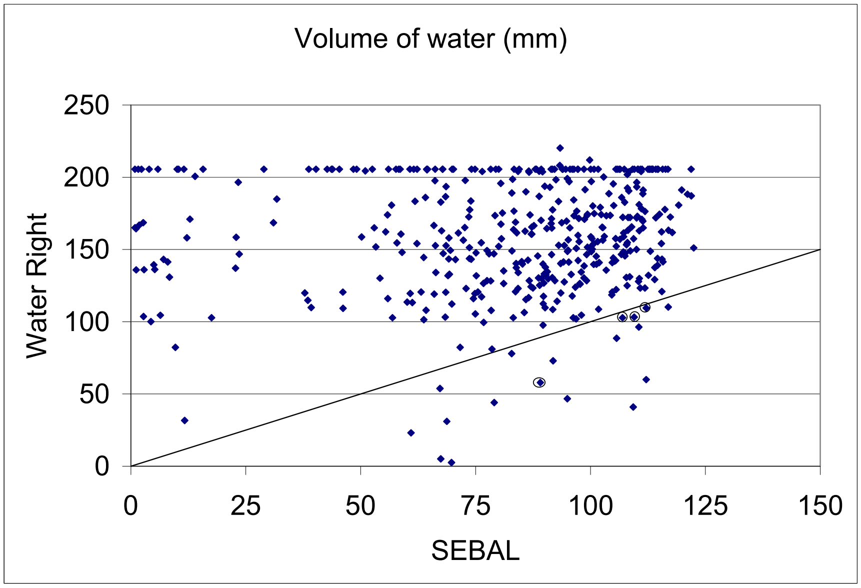

Figure 2. Comparison of SEBAL water consumption values to righted diversion rate.

Results

The eighteen points lying below the diagonal line in Figure 2 were investigated and a summary of findings is provided in Table 1. The table identifies the water right number and provides a ratio of ET to water rights where values greater than 1.0 indicate consumption exceeding authorized diversion amounts. The table also provides comments on the investigation, identifies the validity of the comparison, summarizes WMIS data when available, and lists possible concerns or actions that should be taken.

The comparison was not valid fifteen of eighteen times, usually (11 records) because the selected shape was from the water rights data layer when the valid shape resided in the adjudication recommendation layer. When two active shapes of the same water right existed, the smaller shape was selected, as this was the most likely shape to have been digitized. In most of these cases, the recommended shape was appropriate but larger than the water right shape due to recommending a permissible place of use that usually overlaps or coincides with other rights. In other invalid comparisons, problems include:

- Selecting the version 1 shape when version 1 was closed and version 2 is active (but recommended to be disallowed). In this case it was found that an active overlapping version 2 shape was based on nominal 40-acre tracts and was not digitized to exclude BLM lands as was the version 1 shape.
- Claims for water from Basin 01 overlapped with other Basin 01 rights.
- Two active shapes existed in the water right layer for the same right including license and decree. The license shape was selected over the decree shape. Other rights that were not included in the comparison overlapped the place of use. Also interesting in this case is that the recommendation record is completely missing from the database.
- A license that did not participate in the adjudication overlapped with the right selected for comparison. A change of ownership split the adjudication record but

the licensed right was never split as it should have been. The change of ownership form could not be located for forwarding to the water rights section.

Three of the eighteen comparisons appear to be valid and the amount of water consumption exceeds the authorized amount. One other record had a comparison based on an incorrect shape, but the shape was similar enough to the correct shape so that the comparison is probably close. These four points are circled in Figure 2.

In three of these four cases, the WMIS (Water Measurement Information System) database indicates that recent flow measurements support SEBAL findings with measured diversion exceeding authorized rates by 18 to 75 percent. In the fourth case, the wells used to irrigate the selected place of use also supply water to other rights and places of use, and when reviewed based on the total combined authorized diversion rate, the actual diversion only slightly exceeds the authorized amount. The identified place of use has a very low authorized application rate (1.8 cfs for 320 acres = 0.0056 cfs/acre). Therefore, SEBAL review identified an excessive diversion that likely would not have been discovered by in-field flow rate measurements.

Review also identified four other records where the measured diversion rate (from WMIS) exceeds the authorized rate by 16 to 100%. For three of these, the SEBAL comparisons were not valid due to selecting the wrong shape or because of overlapping rights. For the forth case, the shape was valid but the actual farmed place of use has been adjusted so that land within the shape is now dry and new land outside of the shape is being irrigated.

Conclusions

Review of SEBAL results and comparison of consumed water to authorized diversions for 431 water right place of use shapes has revealed four locations where consumption exceeds authorized diversion. Recent in-field flow measurements support these findings by confirming the diversion’s ability supply this excessive flow rate. However, one of the four locations would likely not have been discovered by in-field discharge measurements alone as the diversion supplies several places of use and only one place has a very low authorized diversion rate. IDWR should determine if any further investigation is necessary and if enforcement proceedings are justified.

This analysis revealed that the process for selecting the appropriate shapefile for comparison is, at least for the group reviewed in detail, not very successful. Only 3 of 27 comparisons were completely valid. The most frequent problems were selection of the wrong shape and overlapping rights usually from a different data layer. However, the majority of these problems occurred in Basin 35 where decreed shapes have not yet been moved to the water rights layer. Reducing the pool of possible shapes should improve the process. Also, because this investigation focused on farms with very low application rates, the high frequency of invalid shapes in the sample may not be representative of the population.

Due to the complexity of overlapping shapes and combined use limits, using this method for comprehensive comparisons will likely be difficult and time consuming. Many rights are coincident, or overlapping but not coincident, and also do not have the combined limit in a data field making comparisons more troublesome. Perhaps further programming will improve comparisons. Also, because all places of use lying within the boundary of a canal company were completely excluded, the comparisons are not comprehensive. Farms irrigated without the use of canal company water, but located within canal company boundaries, were not examined.

This investigation focused on cases where consumed water exceeds the authorized diversion rate. Yet there will be additional instances where the average diversion rate over a period exceeds the authorized rate. In most cases, diversion must exceed consumption; losses from runoff, deep percolation, and some sprinkler spray evaporation will not be included in consumption values. These losses are typically at least ten percent of the total diversion.

It is also possible that SEBAL will indicate consumption that exceeds the actual diversion during the period. It is assumed that consumed water was supplied by diversion during the period. Some of the consumed water was likely supplied from water stored in the soil profile from irrigation during an earlier period, but since these images were taken well into the irrigation season, carryover from the previous year is unlikely. Also, some water may be supplied to growing crops from high ground water levels.

There will also be some level of error in the process. Comparisons between SEBAL and a lysimeter at the Kimberly research station during the 1989 irrigation season revealed disagreement in values for a given image at up to +/- 20 percent. However, the total cumulative ET over the complete irrigation season was in near perfect agreement (Allen, 2002[1]). It is expected that as more experience is gained in applying these methods, the chances of having poor results will decrease.

Recommendations

This project investigated farms where it appeared that water consumption exceeded authorized amounts. Several potential excessive diversions were identified. However, problems with shapefile selection resulted in a number of incorrect comparisons. Effort should be directed toward improving shapefile selection, to improving comparisons where multiple rights are either coincident or overlapping, and to identifying farms located within canal company boundaries that do not use canal water. Since the upper limit of water consumption for this investigation (0.013 cfs/acre) is well below the Department's standard of 0.02 cfs/acre, identifying farms with diversion rates significantly below this standard value may help focus investigations into potential excessive diversions.

SEBAL estimates of water consumption appear accurate and consistent. The Department should consider continued use of SEBAL in future years for determining total annual water consumption and in identifying excessive irrigation diversions.

The Department should take enforcement action on the four identified excessive diversions. The water right owners should be notified of our findings and be offered an opportunity to operate within the authorized limits of their water right(s). Transfer of additional water rights to the place of use, or permissible place of use transfers combining additional rights, may present acceptable solutions. If needed, the diversions should be carefully monitored during future irrigation seasons in order to ensure satisfactory compliance, which may require installation of flow meters and data loggers.

We may also consider investigating additional places of use that are near the threshold diagonal line in Figure 2. It is likely that other rights near to, but above, the diagonal line have average diversions that exceed authorized limits. Since losses, which typically account for 10 percent or more of total diversion, are not included in the determination of consumption, actual diversions are expected to exceed consumption to some extent.

Table 1.

Water Right Num			ET / WR*	Comments/Findings	Valid Comparison	Selected WR instead of Rec shape.	WMIS	Action
1	112	H	27.90	Selected WR POU 1-112H. Other rights with same POU are many, including 41-7008, 41, 10075 and several 01- rights.	no	y		
35	12935		13.48	Query should have selected Recommendation V2 of 35-2617. Total Q 1.76 cfs, 138 acres max = 0.0128 cfs/acre = 131 MAX_MM_H20. Query selected a closed version of recommendation; v2 is disallowed. V2 of -2617 shape had 40-acre tracts, but v1 was okay. Updated V2 shape based on V1 shape less BLM property.	no	n	POD 500023, measured 1.26 cfs. 35-2617 authorizes 1.76 cfs.	
1	1	R	2.67	Many other rights from Snake River, only one selected here.	no	n		
35	4003		2.64	35-4003A was disallowed. Parcel covered by decreed rights 35-7769 & 35-2568 for 7.47 cfs @ 619 acres = 0.0121 cfs/acre = 124 mm.	no	y	Measured 7.47 cfs, 4 pivots & one mini.	
35	2702		2.21	Shape is for 35-2702 WR only; WR 35-2703 overlaps. Recommendations for -2556, -2702, -2703, -2860, -7352 overlap this shape; should use REC shape, 27.59 cfs total for 3344 acres = 0.0083 cfs/acre = 85 mm.	no	y	PODS 200167, 200169, 200170, 200182. Measured 24.31 cfs in 2000, 20.54 cfs in 2002.	Check 3N 36E 34 SW for possible 40 acres unauthorized POU.
35	2090	B	2.03	Shape is for 35-2090B WR only; others overlap. Rec shapes 35-2090B, -2395, -7174, -7924 are coincident. Total Q=9.77 cfs / 782 acres = 0.0125 cfs/acre = 128 mm. May be a good one to re-check with Rec shape used instead.	no	y	PODS 200136 & 200178. Measured max of 11.33 cfs from both wells, 16% above authorized amount.	Measured Q exceeds authorized by 16%.
35	2546		1.87	Shape is from WR, should have used REC. REC shapes 35-2546, 2840, 7288, 7423 coincide, combined 22.43 cfs / 2069 acres = 0.0108 cfs/acre = 111 mm. Recompute ET for larger POU; still may be over or close.	no	y	Four PODs (200123-200126) measured 21.64 cfs, some boosters off.	
35	2860		1.80	See 35-2702. Also see possible illegal pou at 3N36E34 SW	no	y		

36	2061	1.54	Decreed 1.8 cfs / 320 acres = 0.0056 cfs/acre = 58 mm; SEBAL indicates consumption of 89 mm (WR shape 309 acres). 36-2061, 36-2220, 36-2501, 36-8213 from same 2 PODS with max WR Q=7.68 cfs (WMIS measured 7.76 cfs) and total 598 acres for 0.0128 cfs/acre combined.	yes	n	PODs 100343 and 100344 with measured 5.03 + 2.73 cfs = 7.73 cfs, barely above authorized amount.	SEBAL indicates consumption exceeds authorized amount by 49%.
35	7288	1.26	See 35-2546.	no	y		
35	2919	1.25	Two shapes on WR side: License (35-2919) and Decree (35-2919A)? Selected wrong one (license). What happened to the recommendation record (missing from database!!!)? Other overlapping rights.	no	n	Nothing - Slough	
35	13298	1.19	Overlapping license that was not in SRBA (35-08698) not included in SEBAL analysis. Decreed 4.1 cfs / 476 acres = 0.0086 cfs/acre = 88.5 mm. However, combined Q~5.77 cfs for 0.0121 cfs/acre = 125 mm. WMIS measured 7.8 cfs, 35% above authorized.	no	n	POD 200175, measured 7.8 cfs.	Measured Q exceeds authorized by 35%. 35-08698 should be split and proportioned. See email to Jcrabtre 8/29/02.
35	2451	1.15	Shape is from WR, should have used REC. REC shapes 35-2451A, C, and -02639 coincide, combined limit 6.61 cfs / 860 acres = 0.0077 cfs/acre = 79 mm. Recompute ET for REC POU; may exceed authorized. However, license 35-8594 overlaps but isn't coincident and not in AJ. Including 35-8594, max authorized rate is 13.11 cfs for 1193 acres = 0.011 cfs/acre = 113 mm. Mean ET = 111 mm.	no	y	3 PODs. WMIS measured 19.70 cfs (50% above authorized); WR file indicates capacity of 20.75 cfs..	Measured Q exceeds authorized by 50% or more.
35	2321	1.06	Shape is from WR, should have used REC. REC shapes 35-2321, -7323, -2853B, -7559 coincide, combined limit 12.91 cfs / 1088 acres = 0.0119 cfs/acre = 122 mm.	no	y	PODs 200028, 200034. Measured Q=9.59 cfs.	
35	2669	1.06	Shape is from WR, should have used REC. REC shapes 35-2669A & 35-2407 coincide, combined limit 7.96 cfs / 398 acres = .02 cfs/acre. Shapes 35-2669B & 35-7388 coincide @ 0.02 cfs/acre. Measurements are below WR.	no	y	PODs 200297 & 200749.	
35	2609	1.06	Decreed 4.82 cfs / 480 acres = 0.01 cfs/acre = 103 mm. SEBAL mean ET is 109.5 mm. WMIS measured 5.54 & 5.96 cfs (2000, 1998).	yes	n	POD 200168, measured Q = 5.96 (1998), 5.54 (2000).	SEBAL consumption exceeds authorized by 6%. Measured Q exceeds authorized by 24%.
35	7596	1.04	Decreed 1 cfs / 100 acres = 0.01 cfs/acre = 103 mm. 35-7611B, 1.58 cfs, is from same pod at 1"/acre. Total WR Q=2.58 cfs; WMIS measurement 3.05 cfs.	yes	n	POD 600408, gps position (6S30E19SE NWSE) doesn't match WR (SWNESE). Measured 3.05 cfs.	SEBAL consumption exceeds authorized diversion by 4%. Measured Q exceeds authorized by 18%.

35	2460	B	1.02	Should have used recommended shape, but may be over anyway. Two rights, 35-2460B & 35-7155 for 6.36 cfs on 589 acres = 0.0108 cfs/acre = 111 mm. WMIS measured 11.16 cfs for all 3 pods.	no	y	PODs 200288-200290 measured at 5.15+2.72+3.29 = 11.16 cfs.	SEBAL indicates consumption 4% below authorized diversion rate; WMIS measured 75% above authorized rate.
36	7356	C	0.97	Rights 36-7356A & 36-2446 also overlap shape but are not coincident. Total for all rights and both PODs 4.58 cfs/289 acres = 0.016 cfs/acre.	no	n	PODs 100378, 100376. Measured Q 4.81 + 3.02 = 7.83 cfs, 71% above authorized.	Is 7S25E36NE covered by WR? Irrigated but no shape.
35	2840		0.95	Shape is from WR, should have used REC shape although rights now decreed (not moved over yet). New shape will be coincident for 35-2546, -2840, -7288, -7423 for total 22.43 cfs/2069 acres = 0.0108 cfs/acre = 111 mm. WMIS measured total of 21.6 cfs from 4 pods. Has combined acreage but not flow limits.	no	y	Four PODs, measured total 21.6 cfs	
35	9069		0.92	Shape is from WR, should have used REC shape although rights now decreed (not moved over yet). New shape will be coincident for 35-9069 & 35-7192A for total 6.02 cfs/636 acres = 0.0095 cfs/acre = 97 mm. Check this one again later.	no	y	POD 200255 measured 4.46 cfs but does operate with more lines (appx 5.1 cfs).	
35	2335		0.87	35-2335 is only right for irrigation here, 2 cfs / 250 acres = 0.008 cfs/acre = 82 mm. POU has shifted within S1/2 3S32E7 and our shapefile is likely no longer valid. WMIS measured 4.06 cfs, over double the authorized rate.	yes, mostly	n	POD 500702 measured at 4.06 cfs.	Measured Q double authorized.
35	2861		0.77	Shape is from WR, should have used REC shape although rights now decreed (not moved over yet). New shape will be coincident for 35-2861 & 35-7025 for total 6.96 cfs/769 acres = 0.0091 cfs/acre = 93 mm. Check this one again later. WMIS measured 5.21 & 4.21 cfs. Has combined limits.	no	y	POD 200140. WMIS & image indicates recent conversion from handlines (5.21 cfs measured 5/2000) to pivots (4.21 cfs measured in 8/2002).	used v1 shape for v2 and updated 35-7025.
35	7448		0.63	Shape is from rec and okay, although decreed and not yet moved over. Right is 4.58 cfs for 464 acres = 0.0099 cfs/acre = 101 mm. WMIS measured 5.05 cfs, 10% over authorized.	yes	n	POD 500061, measured 5.05 cfs.	
21	2169		0.37	21-2169 is an unclaimed license. 21-2109A license (2.6 cfs) and claim (3.08 cfs) from same POD location. WMIS measured 3.08 cfs.	no	y	POD 200462 measured 3.08 cfs	
35	2038		0.12	Old unclaimed right for irrigation by big southern butte. Image does not indicate irrigation. Should likely be closed.	no	n	None.	
35	7779		0.04	Shape is from WR, should have used REC shape although rights now decreed (not moved over yet). New shape will be coincident for 35-7779 & 35-2503B for	no	y	POD 500010 and BNG200000002. No Q	

				total 4.9 cfs/446 acres = 0.011 cfs/acre = 113 mm. WMIS hasn't measured; the well isn't being used. Has combined acreage but not flow limits.		measurements.
36	2447	B	21.47	Combined limit with 36-2109B, 2.85 cfs / 267 acres, 0.01 cfs/acre = 110mm for selected pou. POD also supplies36-2109A, 36-2447A for total Q of 3.21 cfs. Measured Q 56% over authorized.	n, combined limits	POD 100377, measured Q=5.01 cfs
35	11357		16.92	Combined limit with 35-2475 at 0.02 cfs/acre.	n, combined limits	
35	11213		12.54	Combined limit with 35-02420, 35-07768 at 7.08 cfs / 588 acres = 0.012 cfs/acre.	n, combined limits	POD 500105 measured at 6.96 cfs.
35	11106	B	12.51	Combined limit with 35-2190B at 0.018 cfs/acre.	n, combined limits	

*ET / WR is the ratio of estimated water consumption to maximum authorized quantity.

[1] Allen, Richard G., PhD, P.E. Personal communication during SEBAL Expert Training, August 19-23, 2002 at Idaho State University.